Climate Change: Understanding the past and forecasting the future

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Overview

- Greenhouse warming
- Climate modeling – why can we predict climate if we cant predict the weather beyond ~ 10 days?
- Model evaluation: evidence for greenhouse warming in observations
- Forecasts

Sources

- **My own research**
- **Slides on modeling: Kevin Trenberth, NCAR (Tx!)**
- **Intergovernmental Panel on Climate Change 4rth Assessment report conclusions, Working Group 1: The Scientific basis**
  - UN and World Meteorological Organization
  - Chairs: Susan Solomon, USA and Dahe Quin, China
  - 22 Coordinating Lead Authors, Hundreds of Lead Authors
  - Multiple drafts, thousands of comments from thousands of scientists and government experts
  - Summary for policymakers (SPM) approved sentence by sentence by government representatives, released February 2, 2007

The greenhouse effect

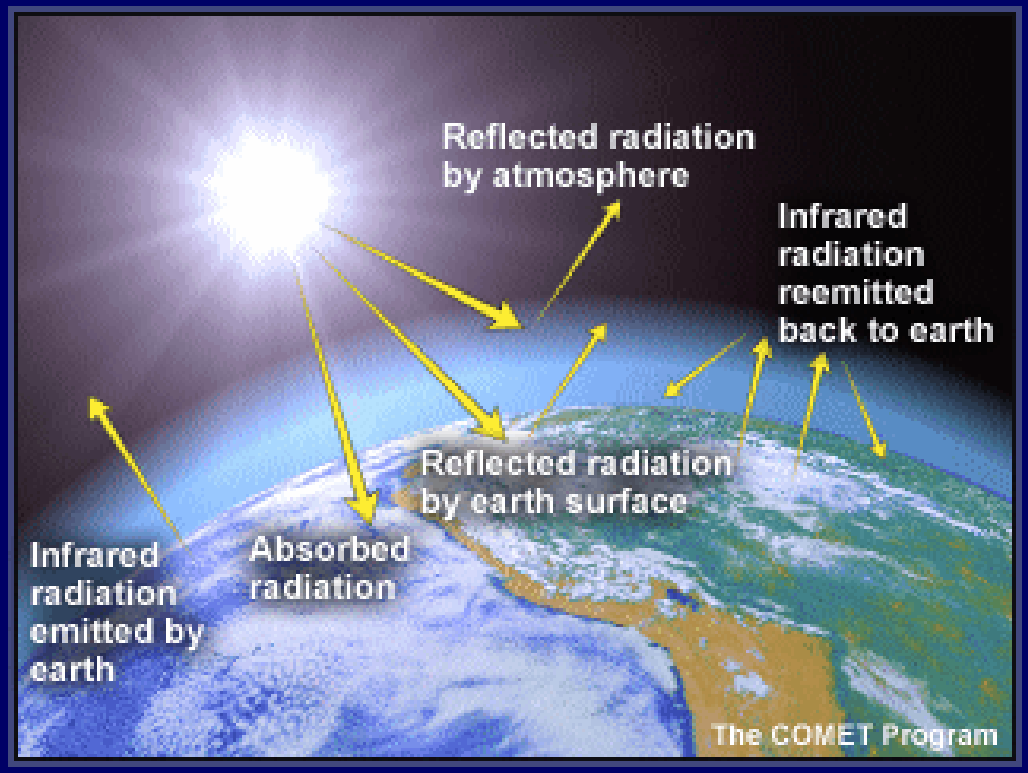
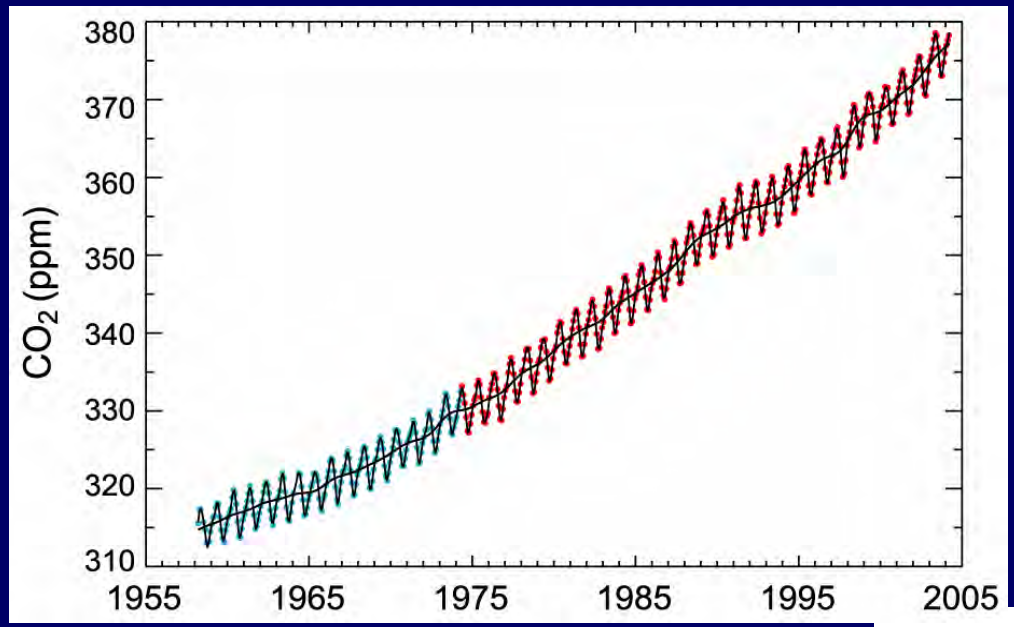


Diagram:UCAR

- Keeps the earth inhabitable
- greenhouse gases: water vapor, CO_2 , methane, N_2O
- Energy budget changes if greenhouse gas concentrations increase
- Direct response: ~ 1K, probably enhanced by feedbacks (e.g., water vapor, clouds)

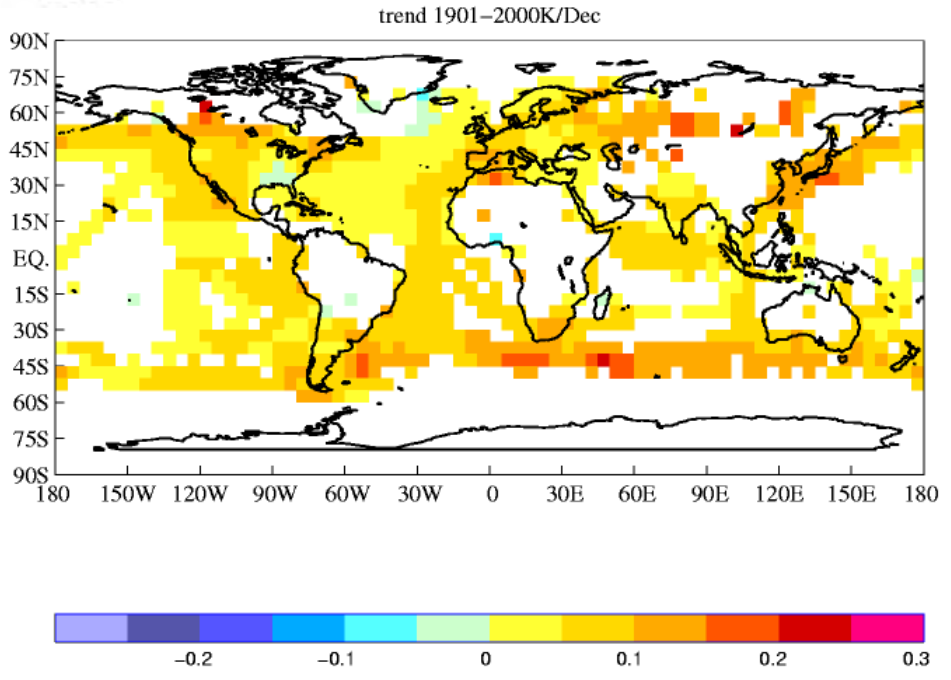


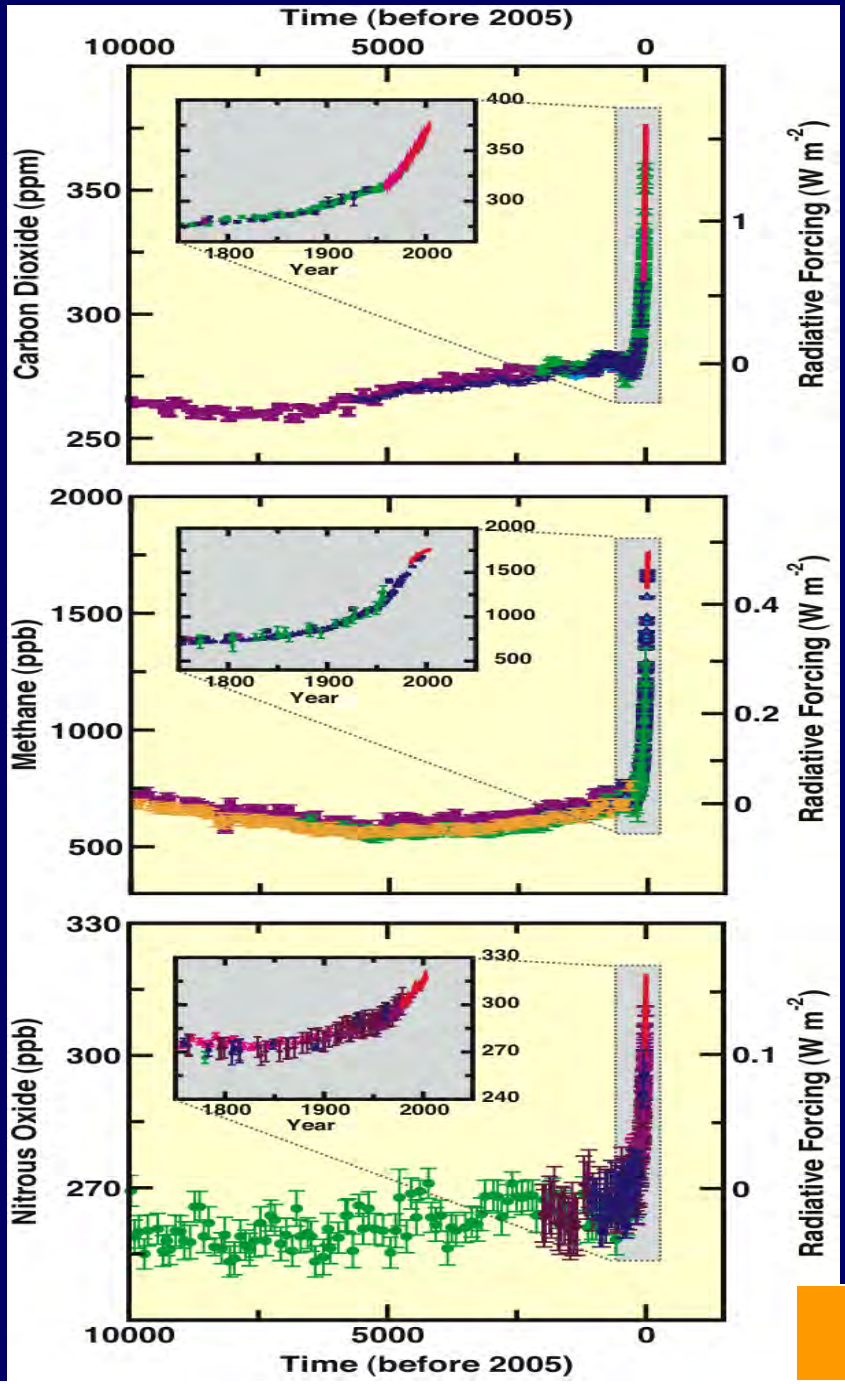
CO2 (Keeling et al.)

Global mean near surface temperature trend over 20th century

How much of the warming is due

to CO_2 increase?





IPCC conclusions on greenhouse gases:

Global atmospheric concentrations of CO_2, methane and N_2O

- have increased as a result of human activity since 1750
- Far exceed pre-industrial values
- CO_2 increase primarily due to fossil fuel use and land-use change
- Influence of solar forcing much smaller

Fig. SPM-1

RADIATIVE FORCING (RF) [1750-2005]: measure of change in energy balance

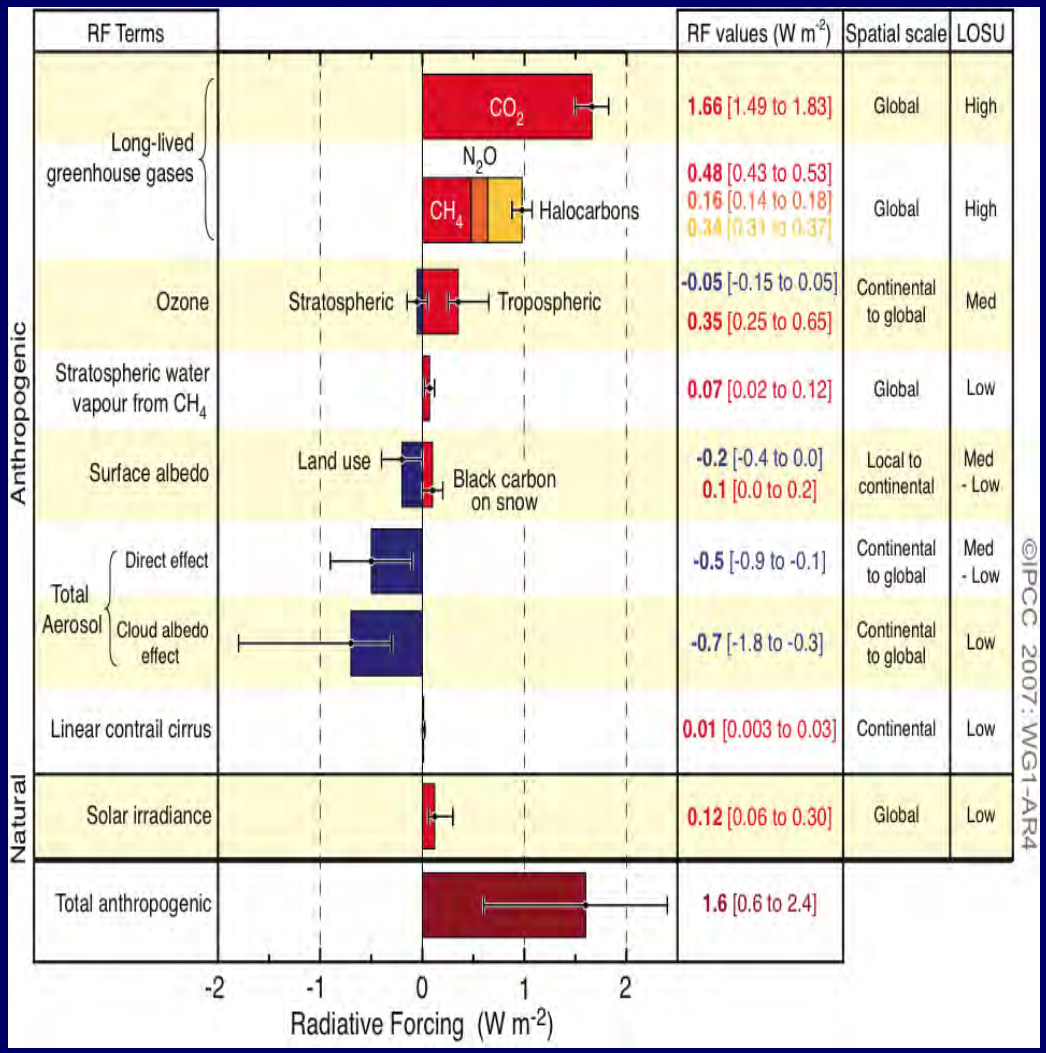


Fig. SPM-2

Very high confidence that globally averaged net effect of human activities since 1750 has been one of warming,

- net anthropogenic radiative forcing (RF) of 1.6 [0.6 to 2.4] W/m^2 (best estimate and 90% range)
- Solar forcing: much smaller than greenhouse gas forcing

Climate models

- Are needed to predict climate effect of these changes
- Tens of models worldwide

Climate modelling (TK)

Take a large almost round rotating sphere 8,000 miles in diameter.

Surround it with a murky, viscous atmosphere of many gases mixed with water vapor.

Tilt its axis so that it wobbles back and forth with respect to the source of heat and light.

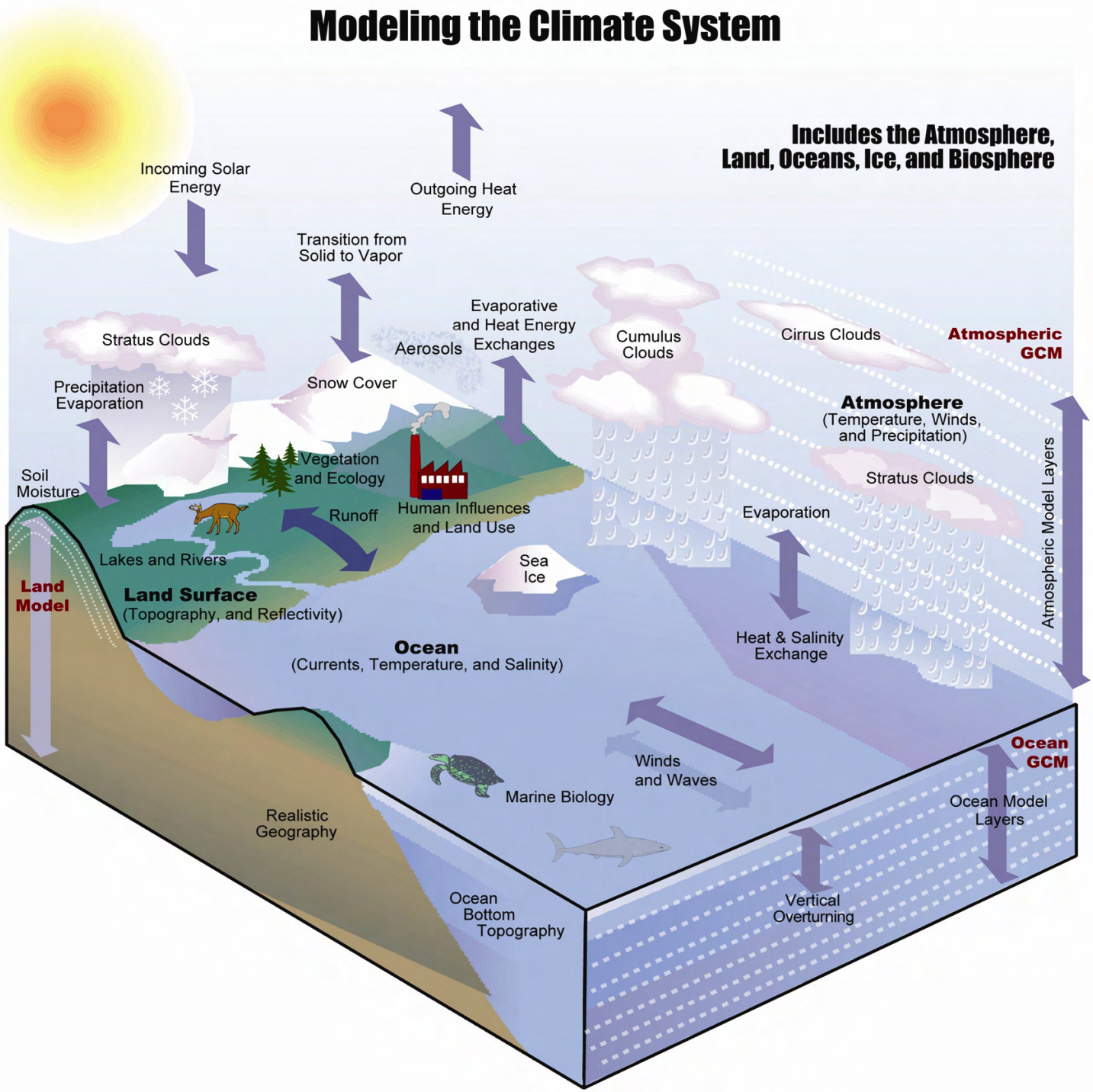
Freeze it at both ends and roast it in the middle.

Cover most of the surface with a flowing liquid that sometimes freezes and which constantly feeds vapor into that atmosphere.

Condense and freeze some of the vapor into clouds of imaginative shapes, sizes and composition.

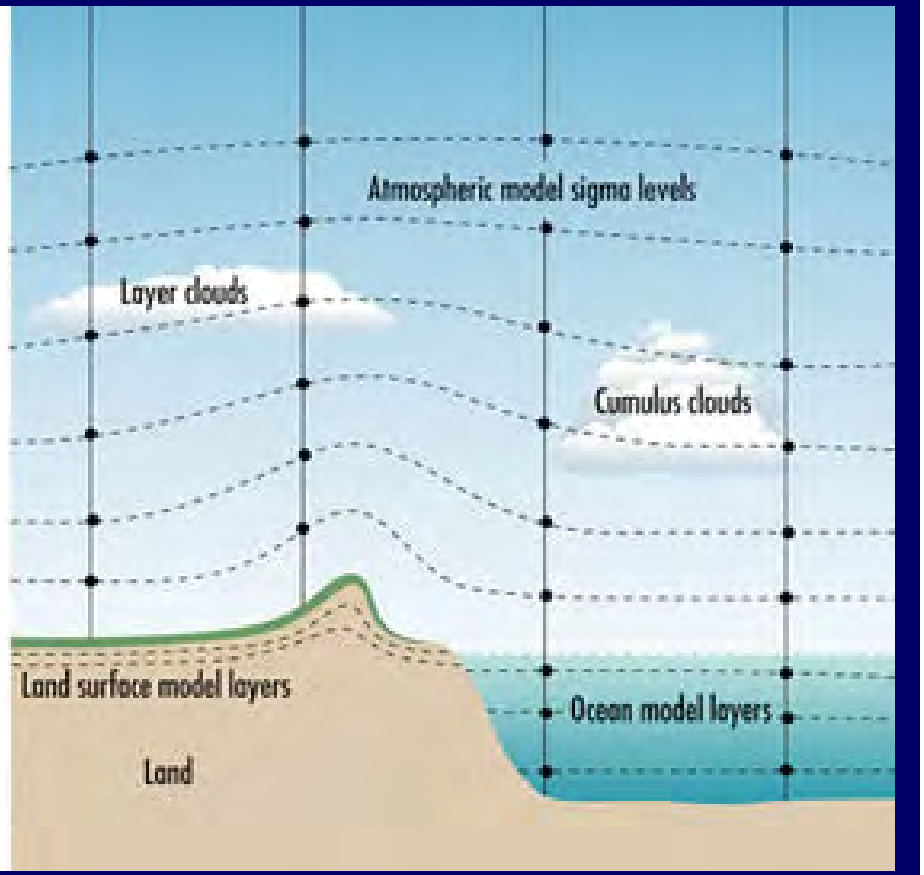
Then try to predict the future conditions of that atmosphere for each place over the globe.

Modeling the Climate System



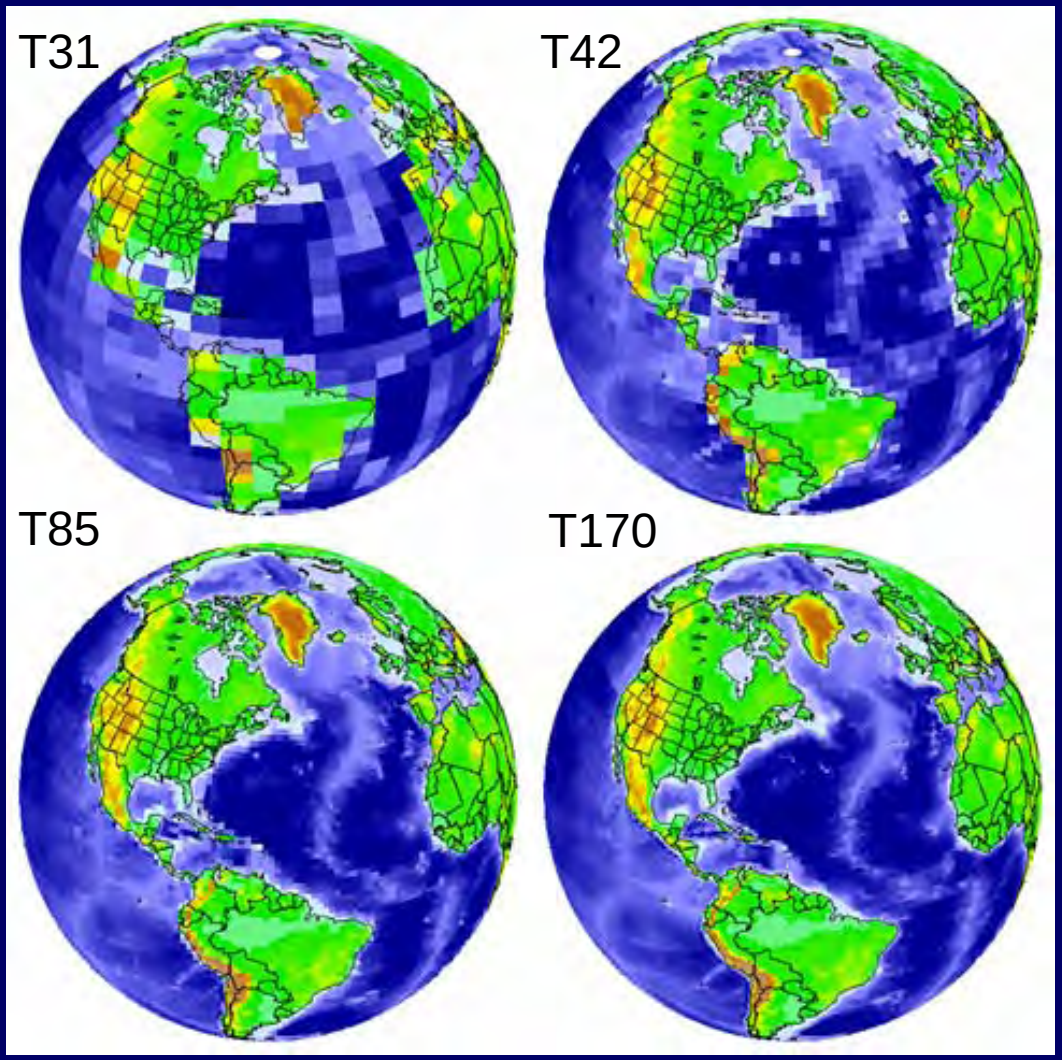
Karl and Trenberth 2003

Climate modeling



- Slice ocean/atmosphere into 3-D boxes and discretise
- Solve conservation equations for mass, heat, momentum within in climate system component
- create an interface between climate components and exchange fluxes

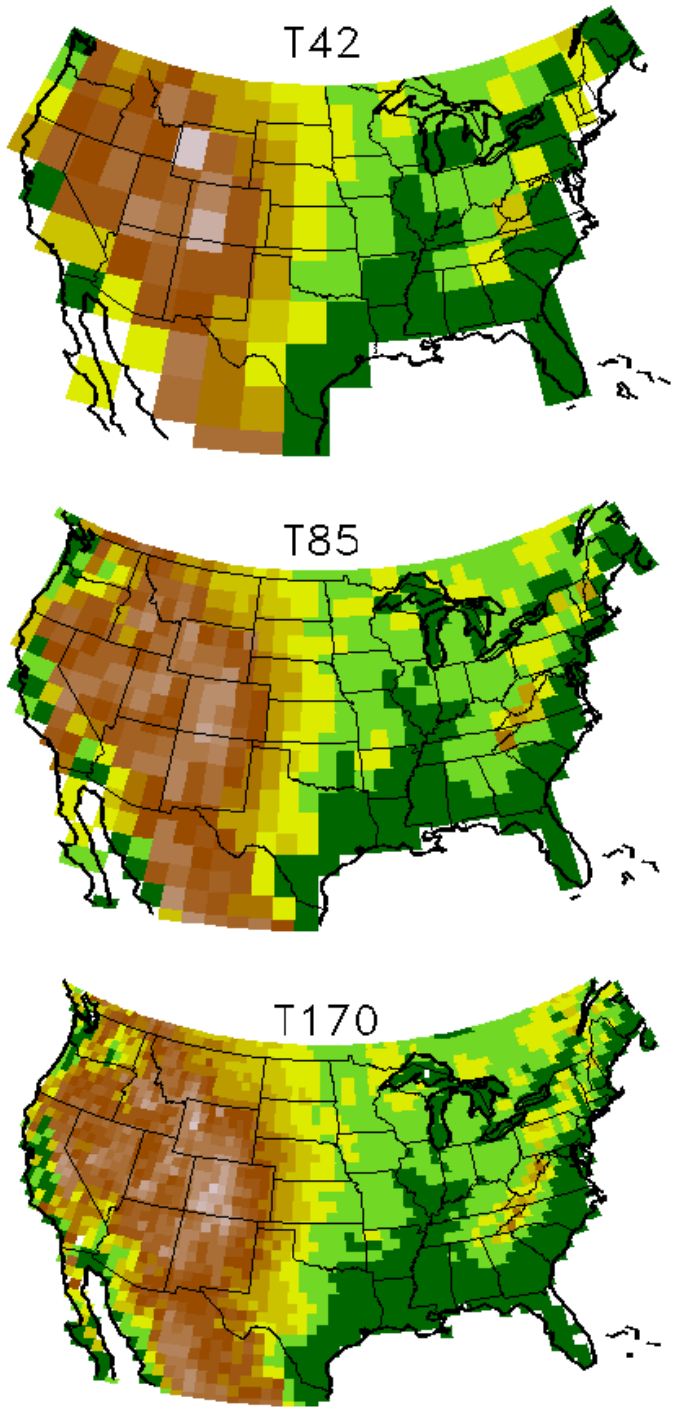
Horizontal Discretization of Equations



← Most IPCC models

Horizontal Discretization of Equations

The partial differential governing equations are discretized using about 30 to 60 vertical layers and a horizontal grid ranging in size from 2.8° latitude (300 km) (T42 spherical harmonic spectral depiction) to 1/3° latitude (35 km) (T341).



Strand

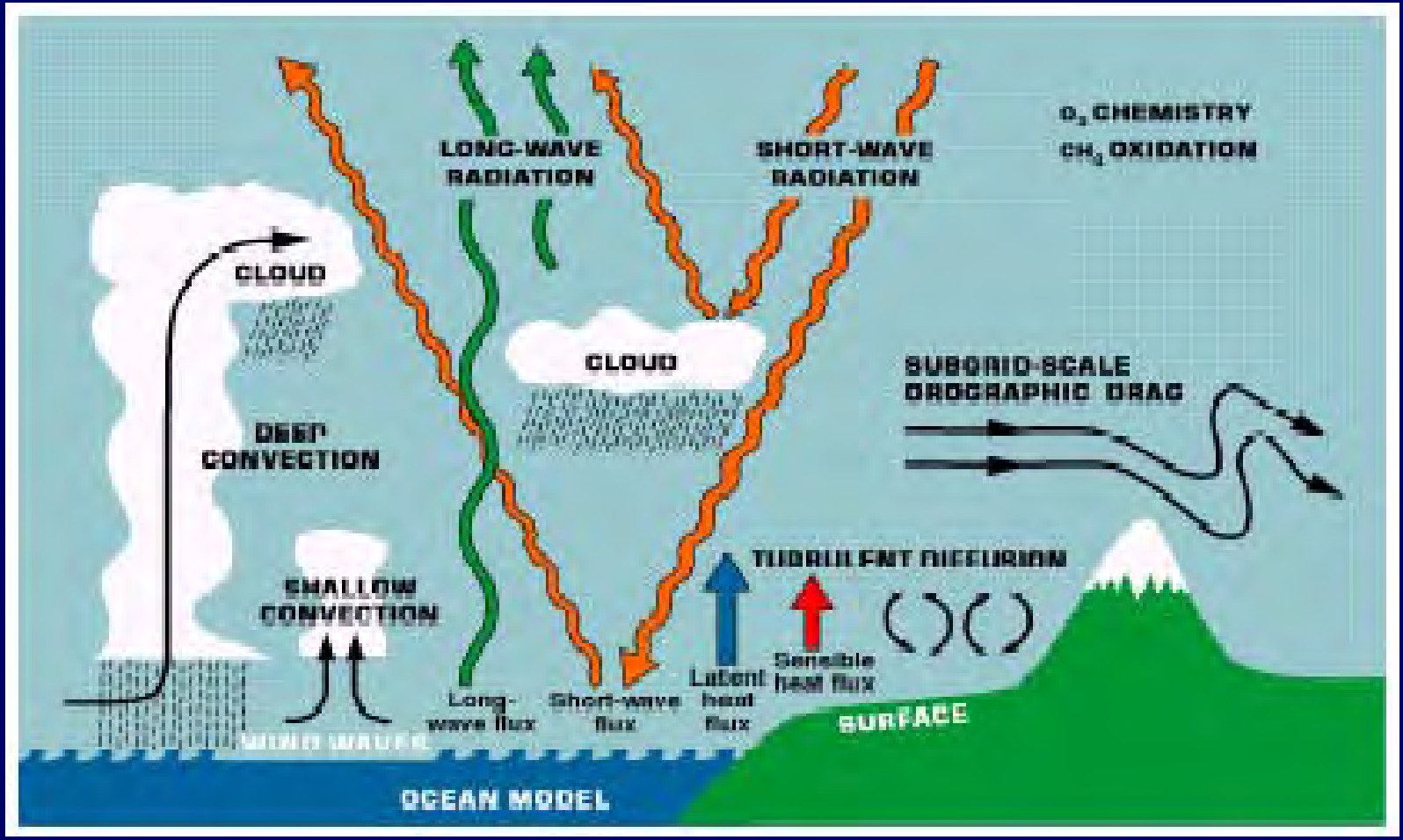
Physical Parameterizations

Processes that are not explicitly represented by the basic conservation and state equations on the grid of the model need to be *parameterized*.

- **Sub-grid-scale processes: Convection, boundary layer friction and turbulence, gravity wave drag (transport momentum, sometimes heat)**
- **Processes that contribute to internal heating (non-adiabatic, such as radiative transfer and precipitation)**
- **Processes involving additional variables (e.g. land surface processes, carbon cycle, chemistry, aerosols, etc)**

Slingo

Parameterized Processes

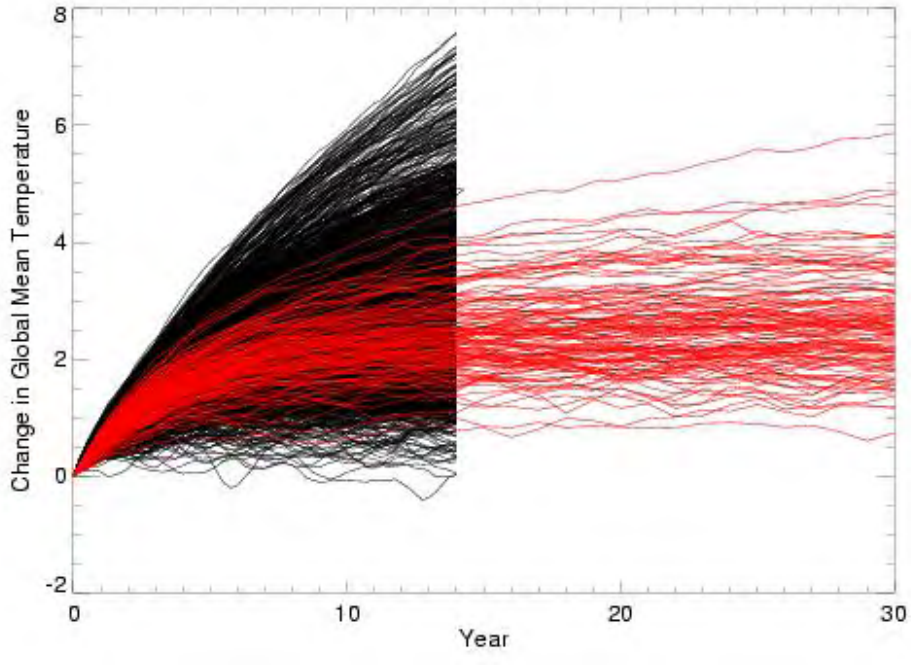


Slingo

Climate modeling

- Climate models produce weather and climate variations
- Model parameters get tuned to reproduce climatological mean state
- Presently forefront: uncertainty in parameters

climateprediction.net



Weather and Climate

Weather:

What you get

Initial conditions

Can be predicted only days in advance

Climate:

What you expect

Ocean initial conditions and Boundary conditions

Can be predicted seasonally with ocean initial conditions eg El Nino

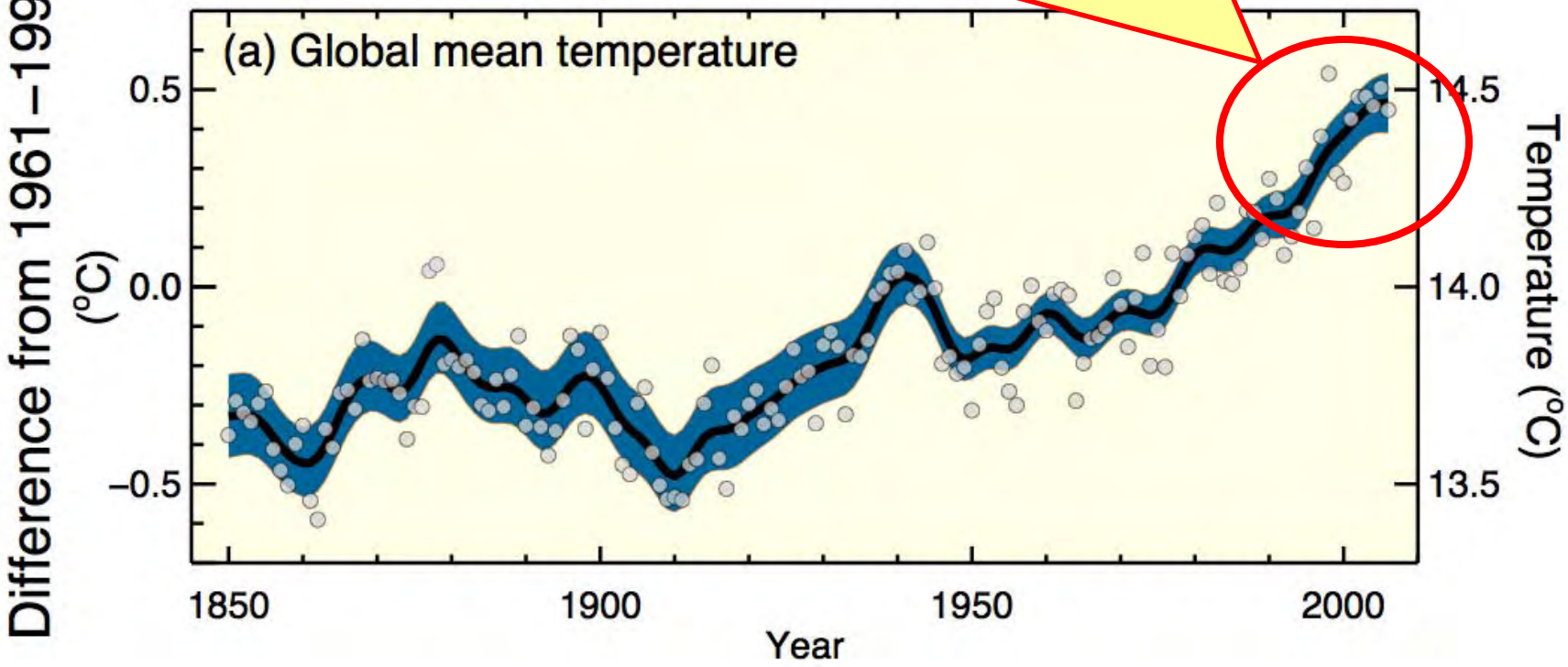
Longer for boundary conditions eg CO_2 changes, or Last Glacial Maximum conditions

Climate model evaluation

1. Compare their simulations of the seasonal cycle of temperature, rainfall, sea level pressure, modes of variability (El Nino) with observations (done extensively, good for temperature, slowly improving for rainfall)
2. Compare changes simulated over the 20th century with observations
3. Evaluate how much of the observed changes is due to external drivers

Observed climate changes: Surface temperature

Warmest 12 years:
1998,2005,2003,2002,2004,2006,
2001,1997,1995,1999,1990,2000

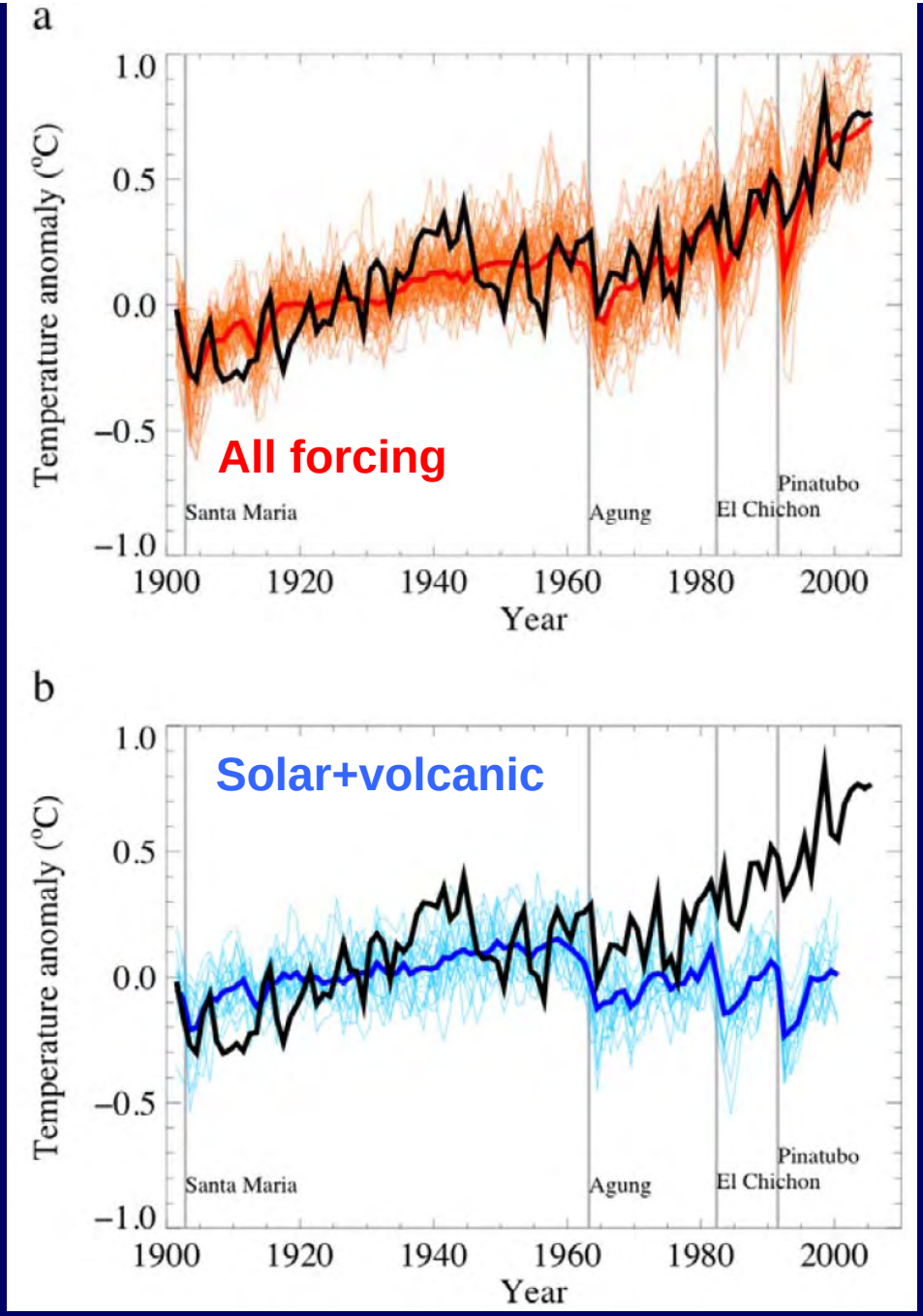


SPM-3a

Climate models can simulate this

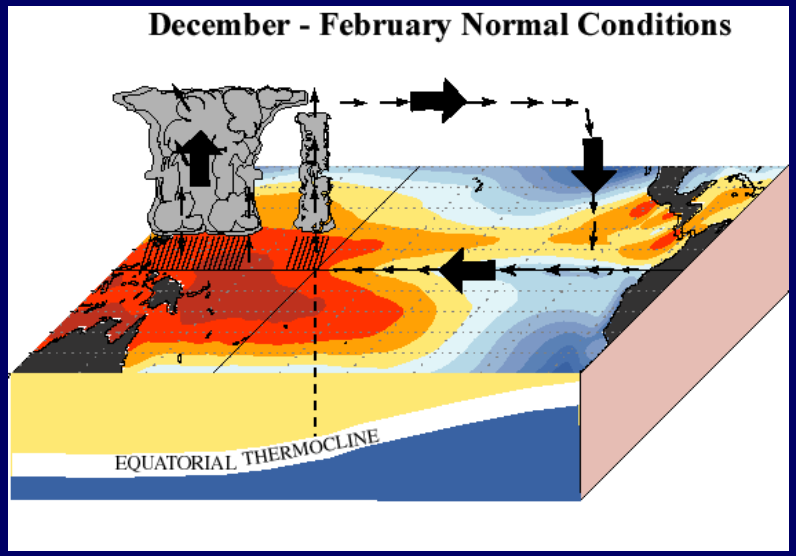
- Compared between observations and climate model simulations (very many different models, different forcing representations

Are we getting this agreement for the right reason?



TS-23 and Chapter 9

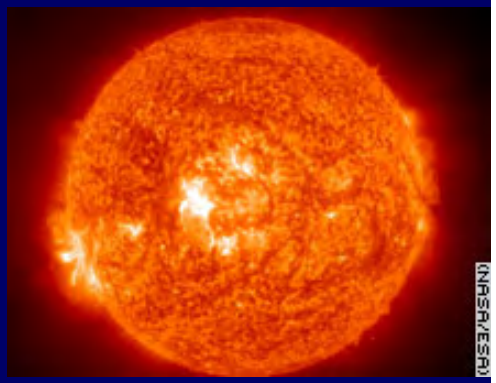
For this, we separate different climate influences in observations based on their pattern



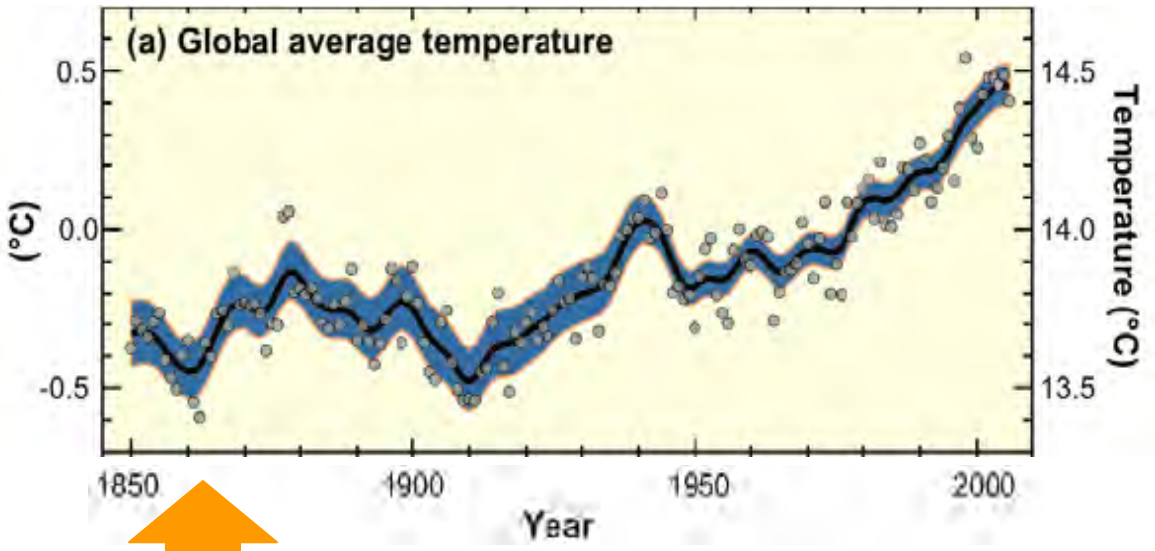
El Nino normal conditions

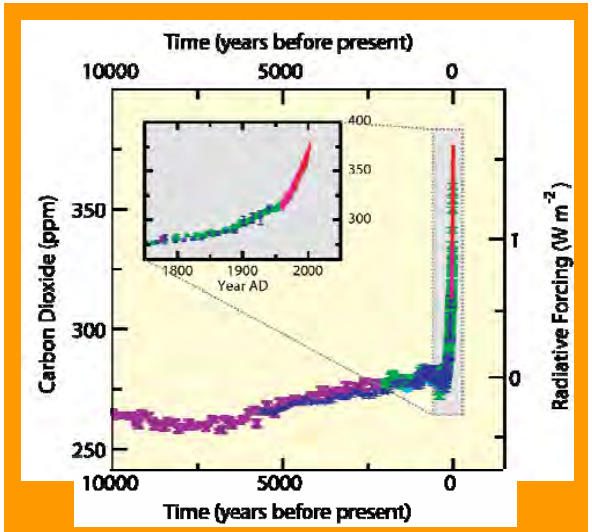
Pinatubo, 1991

Krakatau, 1883



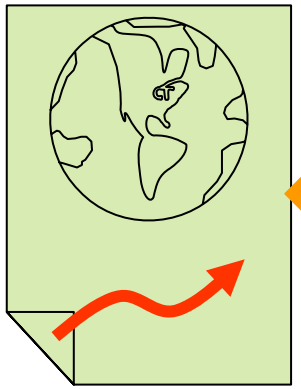
Attribution Process

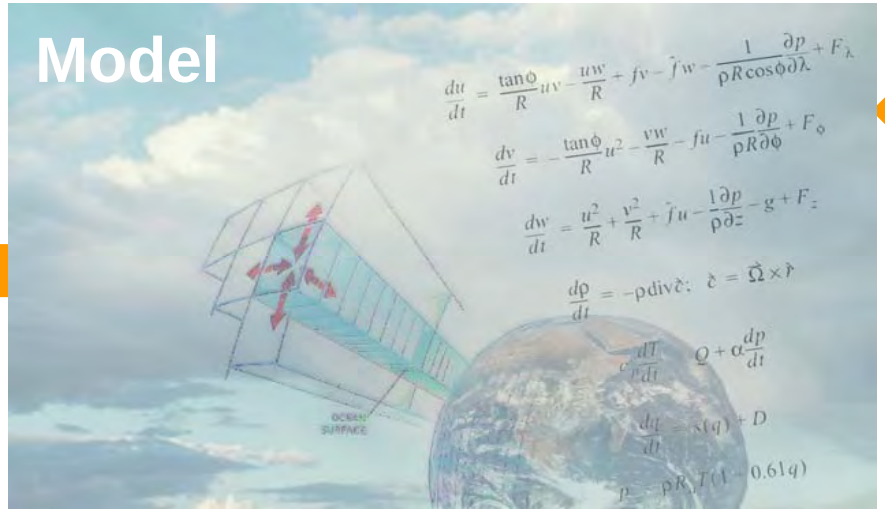




- other GHGs
- aerosols
- volcanic
- solar
- natural internal

Multi-regression, sn optimized



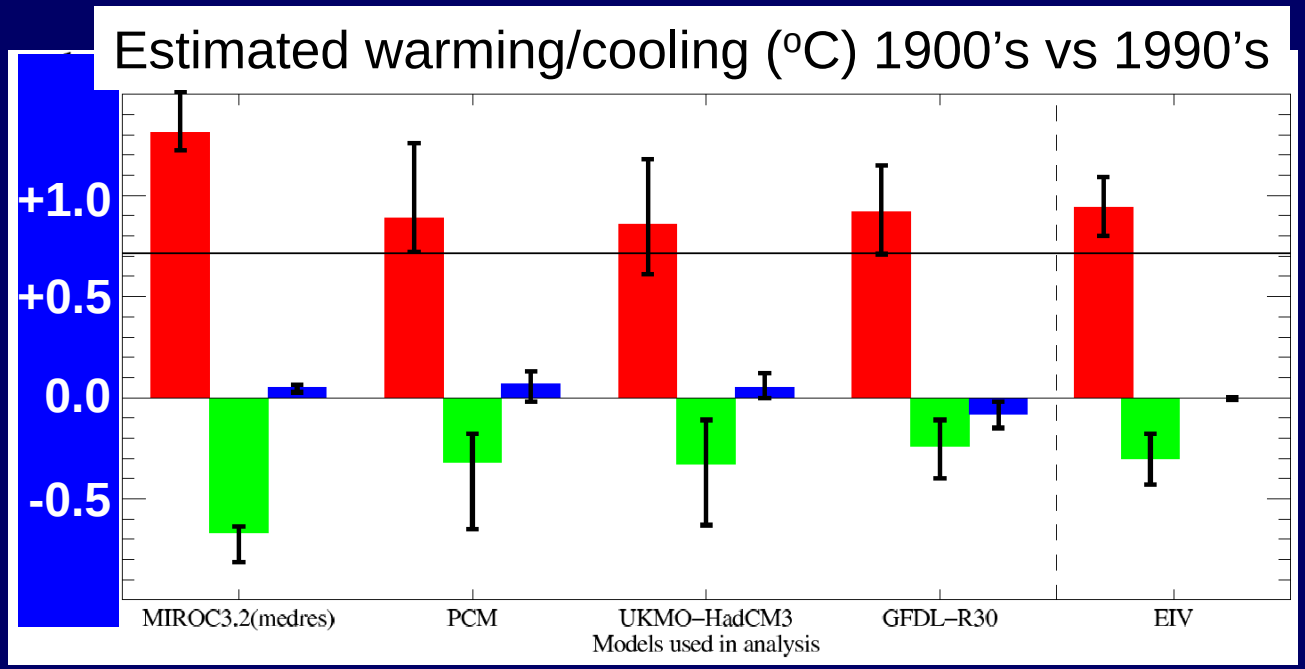


Attribution results:

GHG

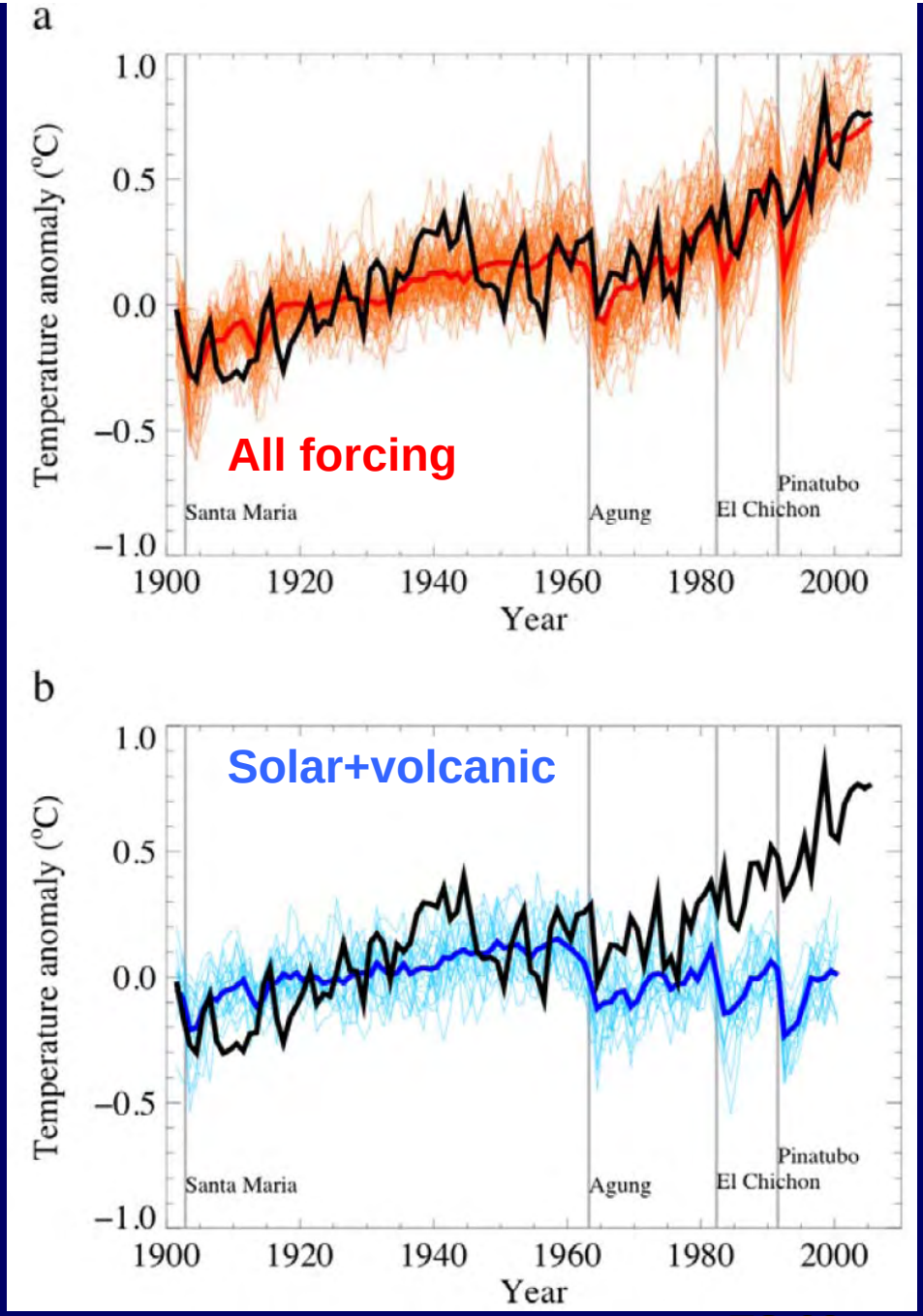
Other anthropo genic

Natural

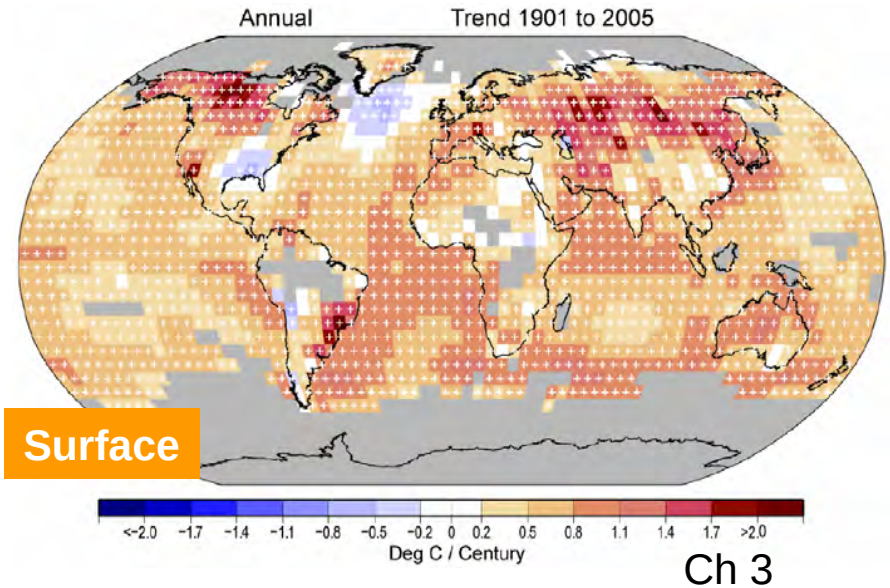


"It is *very likely* that anthropogenic greenhouse gas increases caused most of the observed increase in globally averaged temperatures since the mid-20th century."

- **Anthropogenic greenhouse gas increases *very likely* caused most of the observed warming since mid-20th century**

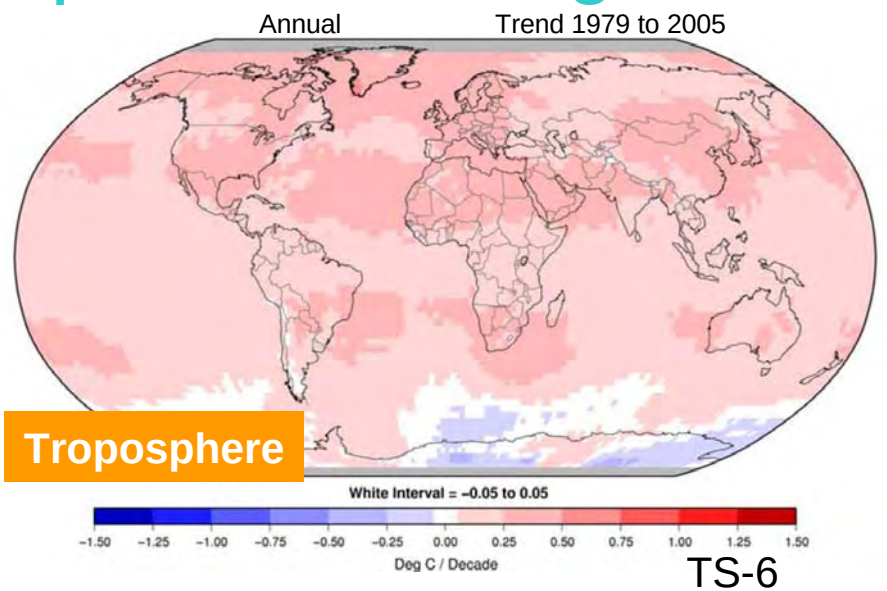


Observed widespread warming



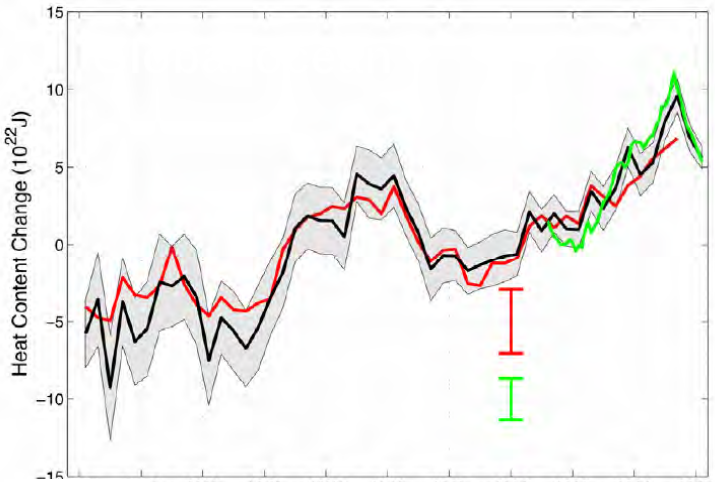
Surface

Ch 3



Troposphere

TS-6

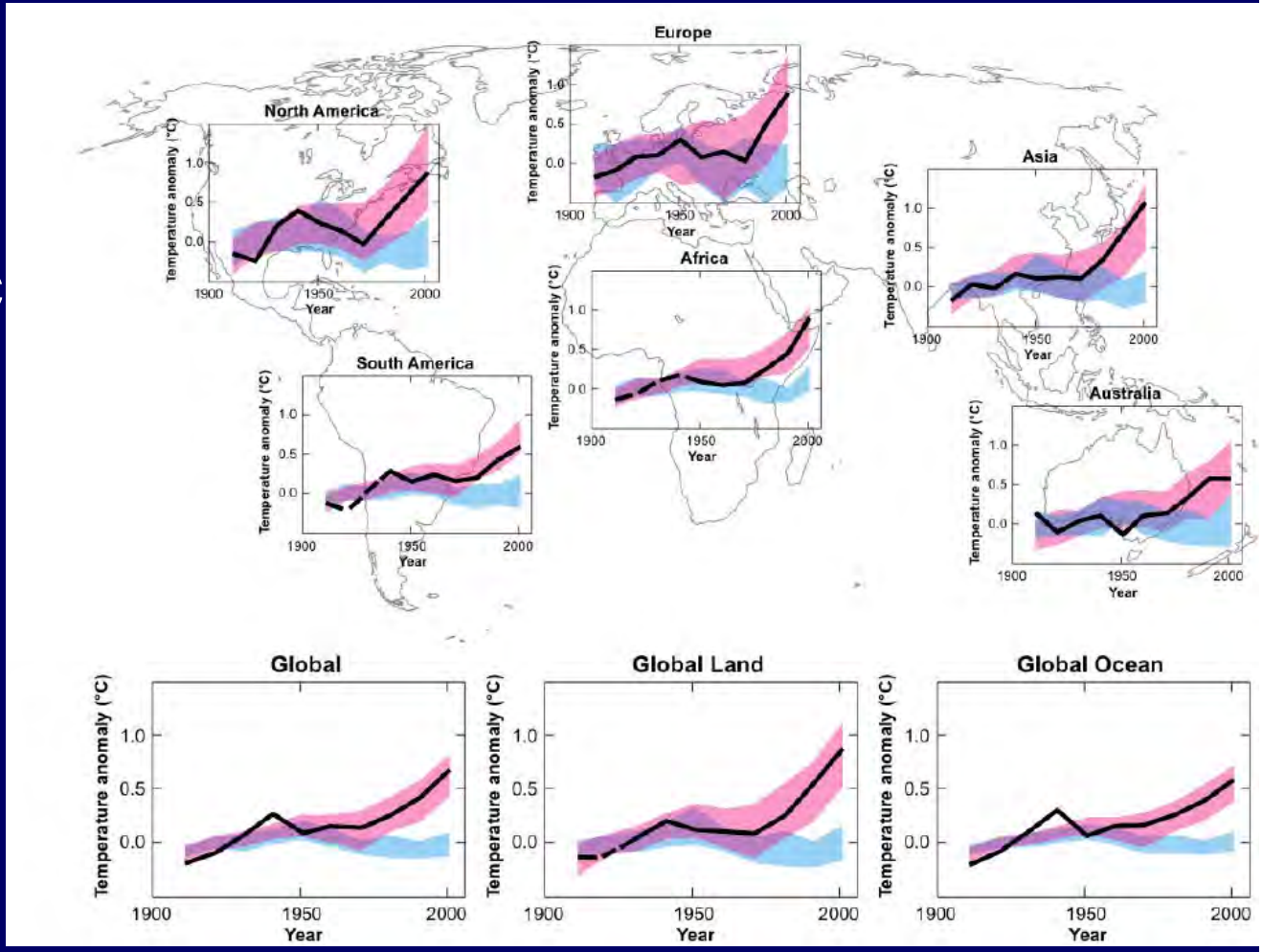


- **extremely unlikely without external forcing**
- **very unlikely due to known natural causes alone**

Continental warming

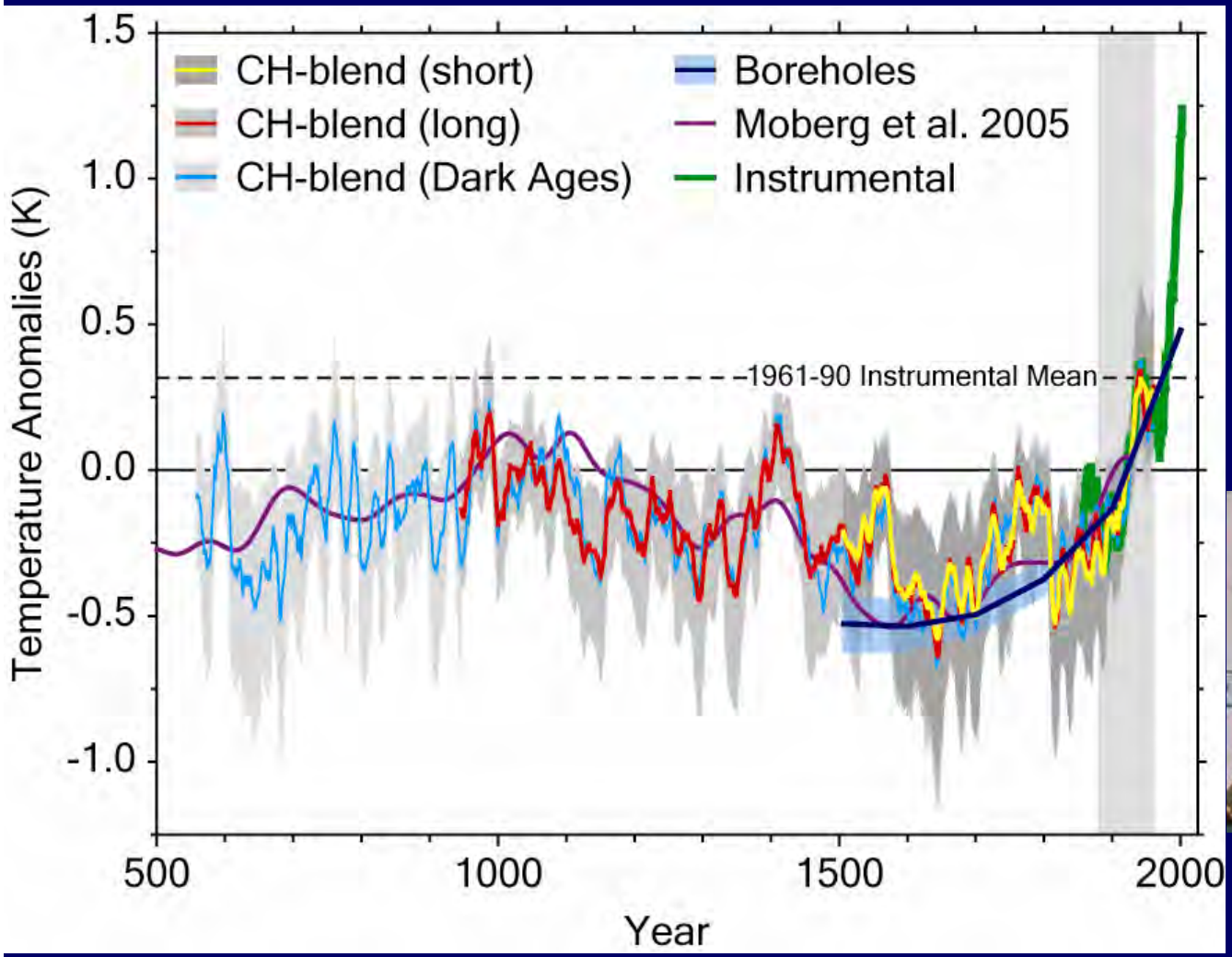
SPM-4

likely **shows a significant anthropogenic contribution over the past 50 years**



— Observations ■ All forcing ■ natural forcing

Didn’t temperatures vary before?



-Several reconstructions of Northern Hemispheric temperature

- using:

NH 30-90N temperature; Hegerl et al., 2007

But we know what caused these variations! (kind of)

Model simulated response compared to range of reconstructions

Other things we can evaluate models with

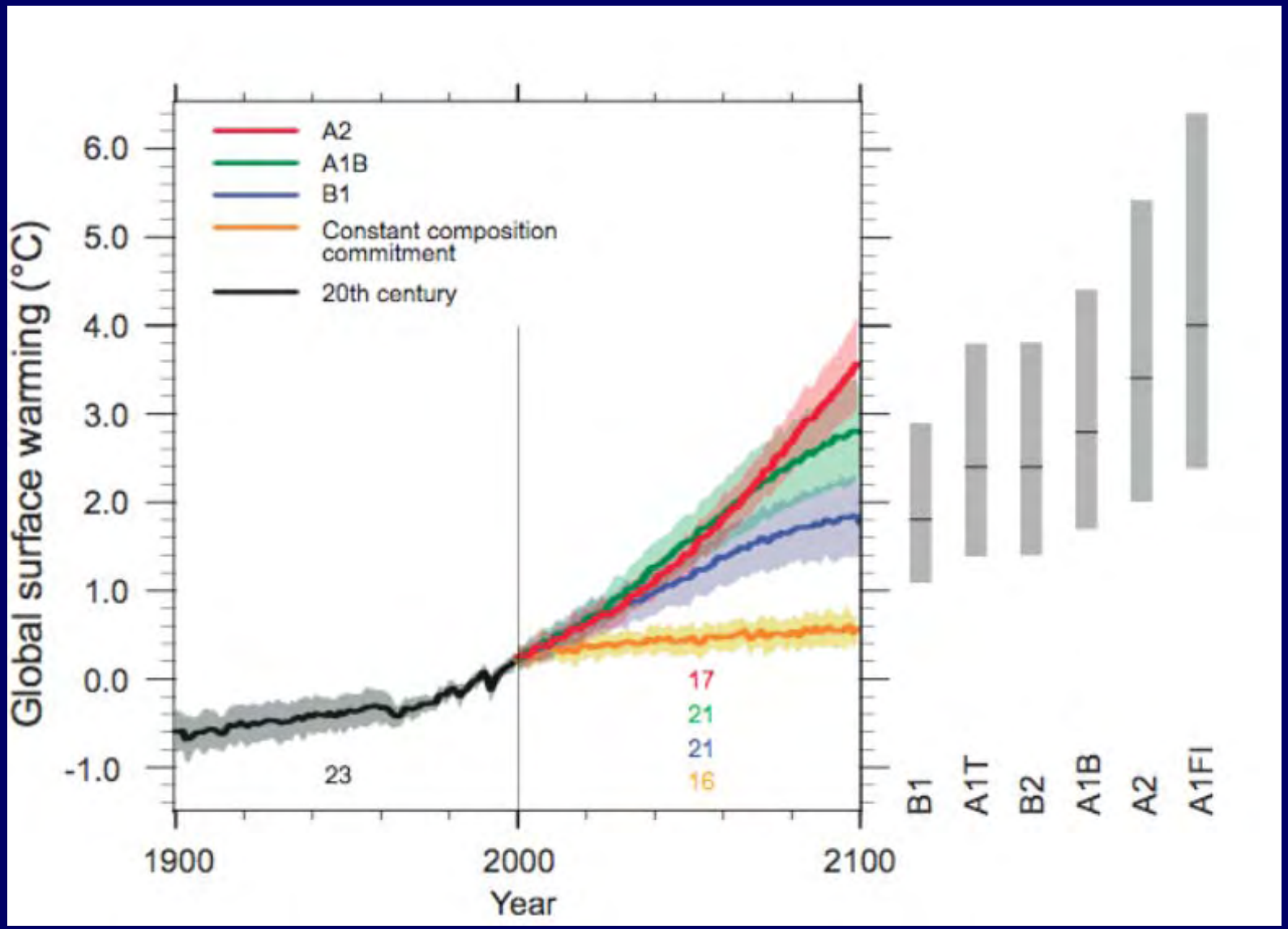
- **Last Glacial Maximum: put huge ice sheets onto NH, lower CO2, change vegetation and put dust into atmosphere; and then compare tropical ocean temperatures with reconstructions**
- **Mid-Holocene: produce wet conditions in Sahel by changes in earth's orbit**

Will it continue to warm?

- Climate is sensitive to greenhouse gas increases: equilibrium climate sensitivity very likely > 1.5°C
- We know that from 20th century warming, Ice Age cooling, last millennium, and studies of model uncertainty
- "likely" (66%) range of future global mean temperatures

Scenarios

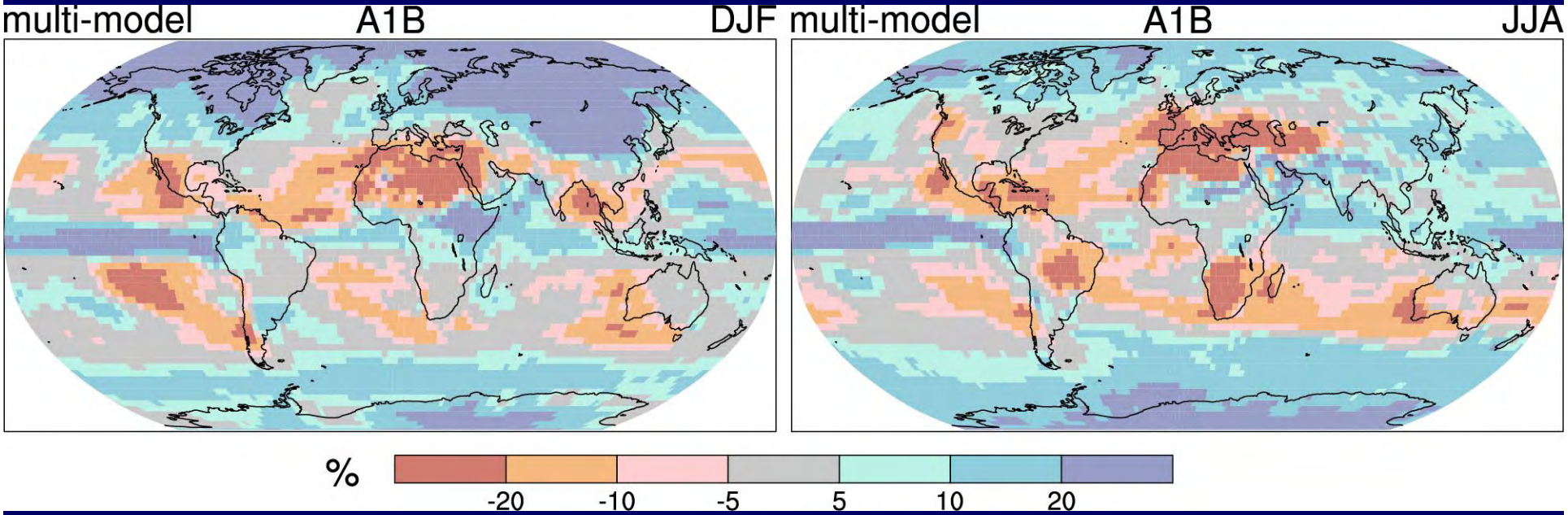
- Give various estimates of how economies and with them emissions might evolve WITHOUT constraining greenhouse gas emissions



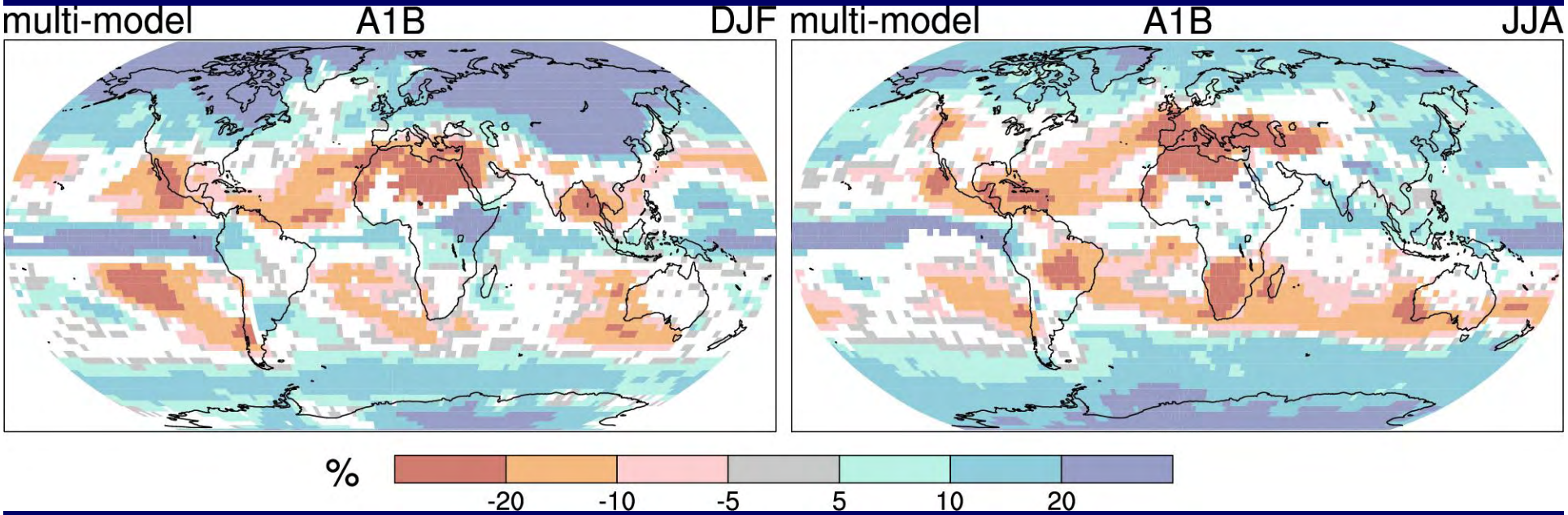
Future projections: Different scenarios, no mitigation

SPM 7

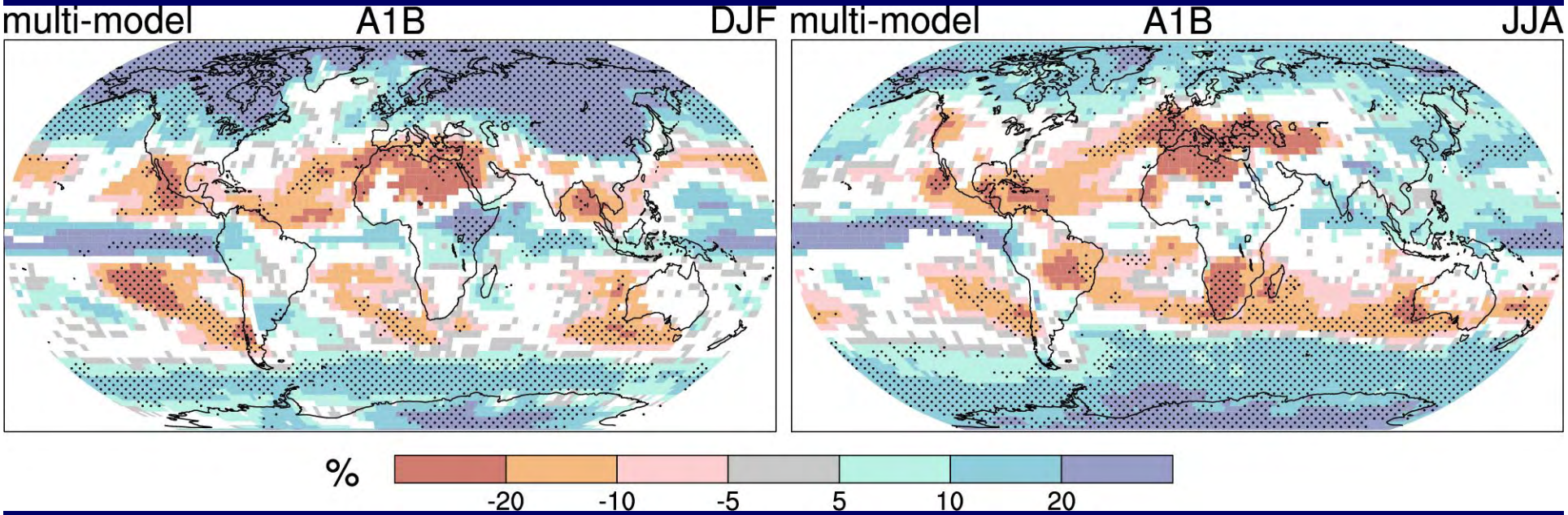
Rainfall will change



Multi-model average precipitation % change, medium scenario (A1B), representing seasonal precipitation regimes, total differences 2090-99 minus 1980-99



White areas are where less than two thirds of the models agree in the sign of the change



Stippled areas are where more than 90% of the models agree in the sign of the change

Precipitation increases very likely in high latitudes

Decreases likely in most subtropical land regions

This continues the observed patterns in recent trends

Circulation has already changed

- Westerlies in both hemispheres have increased
- Anthropogenic forcing has likely contributed
- Affecting storm tracks, winds and temperature patterns

TS Box 3.1

And…

- Sea level expected to rise 20-60 cm depending on scenario and sensitivity
- sea level change based on ocean warming and melting of ice sheets, but not including future rapid dynamical changes in flow (ie upper limit uncertain)
- We don't know too much about hurricanes (most intense will likely increase)
- Areas affected by drought will likely increase
- Heavy rainfall, heat waves very likely to increase